GPS Innovation Alliance

July 13, 2017

Via ECFS and IBFS

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: Written *Ex Parte* Presentation

LightSquared Request to Modify Its ATC Authorization, **IB Docket No. 12-340**; **IBFS File Nos. SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SAT-MOD 20101118-00239; SES-MOD-20121001-00872**; LightSquared Technical Working Group, **IB Docket No. 11-109**; **DA 16-442**

Dear Ms. Dortch:

The GPS Innovation Alliance ("GPSIA") respectfully submits this *ex parte* filing on the appropriate standard for evaluating harmful interference to Global Navigation Satellite System ("GNSS") devices in order to provide context for the Commission's consideration of recent test results published by the National Advanced Spectrum and Communications Test Network ("NASCTN").[1]

The NASCTN tests contribute to the available technical information on the measurement of interference to GNSS devices.[2] The test results provide both direct and indirect support for the use of the historic and well-established standard for determining harmful interference – whether an interfering signal produces a 1 dB decrease in the Carrier-to-Noise Power Density

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1 WILLIAM F. YOUNG, ET AL., LTE IMPACTS ON GPS, NIST (2017), http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1952.pdf ("NASCTN Report").

2/ NASCTN's goal was to:

> "establish a test method to investigate the impact of adjacent band long-term evolution (LTE) transmissions on global positioning system (GPS) L1 receivers in tracking and reacquisition modes. . . . [T]he resulting test method and data . . . could be used to: 1. establish the integrity of this and other test methods and ensure the quality of the collected data, including detailed uncertainty analysis of both the test conditions and the device under test (DUT) response, 2. enable a connection to previous testing efforts focused on adjacent band activity impacts on GPS device performance, and/or 3. support additional, in-depth testing by other interested parties on measurand behavior as reported by the [Devices Under Test]. The methods, testing, results, and analyses neither assumed nor identified pass/fail thresholds." NASCTN Report at 1.

Ratio ("C/N_0") of the affected receiver.[3] The standard is also amply supported not only by precedent and use in applicable technical standards but is also based upon well understood technical characteristics of GNSS receivers and the impact of noise on the performance of these receivers, all of which remain valid today.

I. The 1 dB Standard Remains the Appropriate Standard for Evaluating Harmful Interference to GNSS Receivers

The NASCTN results provide direct support in the form of test data which establish a direct correlation between decreases in C/N_0 of the tested receivers and degradation in measured key performance indicators ("KPIs"). The report provides indirect support by highlighting the extreme complexity of measuring the effect of interfering signals on the selected KPIs of GNSS devices and the limitations of the data obtained from such tests. For example, while the vast majority of GNSS receivers are designed and intended for mobile operation (as might be expected for devices that are intended to provide location information while moving in vertical and horizontal space), the NASCTN test method only analyzed the effects of interfering signals on stationary GNSS devices. Moreover, for all of the effort put into the testing, data were collected on only four KPIs (and even these were not available for all devices). No tests were conducted to determine the effect of any detected degradation in these indicators on the actual performance of the critical applications for which the tested GNSS receivers are used, such as precise machine control or aviation navigation. Nor is it at all clear how such tests could ever be performed in a rigorous and reproducible manner since such applications operate in dynamic real-world environments, not a laboratory.

II. GPSIA Reiterates Its Members' Previously Stated Positions with Respect to the Technical Parameters Which Have Been Agreed Upon with Ligado

As noted in the applications for modification submitted by Ligado Networks LLC ("Ligado") for its Mobile Satellite Service ("MSS") licenses,[4] each of GPSIA members Deere, Garmin and Trimble have negotiated agreed-upon technical parameters for terrestrial use of some or all of Ligado's licensed MSS spectrum. GPSIA refers the Commission to the applications and associated filings for the details.[5] In general, the agreements set forth (1) technical requirements

[3] For ease of reference, this standard is referred to as the "1 dB standard."

[4] *See* Applications of LightSquared Subsidiary LLC, Narrative, IBFS File Nos. SAT-MOD-20151231-00090, SAT-MOD-20151231-00091, and SES-MOD-20151231-00981 ("Modification Applications"). In this *ex parte*, we use the term "Ligado," "New LightSquared," and its subsidiary "LightSquared Subsidiary LLC" interchangeably.

[5] *See, e.g.*, New LightSquared, *Ex Parte* Presentation, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SAT-MOD-20101118-00239; SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; SES-RWL-20110908-01047; SES-MOD-20141030-00835 (Dec. 8, 2015) ("LightSquared December 8 *Ex Parte*"); New LightSquared, *Ex Parte* Presentation, IB Docket No. 12- 340; IB Docket No. 11-109; IBFS File Nos. SAT-MOD-20101118-00239; SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; SES-RWL-20110908-01047; SES-MOD-20141030-00835 (Dec. 17, 2015) ("LightSquared December 17 *Ex Parte*"); New LightSquared, *Ex Parte* Presentation, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SES-MOD- 20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091 (Feb. 3, 2016).

pertaining to terrestrial operations on frequencies from 1627.5 MHz upwards; and (2) limitation on use of the 1545-1555 MHz band solely for satellite downlink purposes, and agreement that Ligado will not seek any terrestrial authorization for the 1537-1555 MHz band.[6] On behalf of these members, GPSIA refers the Commission to the agreements and acknowledges the continued adherence of Deere, Garmin and Trimble to the positions set forth in the agreements.

Beyond the specific technical resolutions in the agreements, there are policy issues of general applicability that have been the subject of extensive controversy in the above-referenced dockets for which the parties to the settlement agreements have "agreed to disagree." One such issue is the appropriate standard for determining harmful interference to GNSS devices. The agreed upon technical requirements do not constitute agreement with, or endorsement of, any party's position on the correct metrics or standard for determining the potential for harmful interference to GNSS devices and applications. Whatever action the Commission takes with regard to the specific Ligado Modification Applications in light of the parties' agreements, it continues generally to have a responsibility to ensure that newly proposed or modified terrestrial operations do not cause harmful interference to GPS and other GNSS systems, and GPSIA and its members continue to believe that the 1 dB standard is the appropriate standard.

III. <u>The NASCTN Test Data Support the 1 dB Standard</u>

GPSIA and its members believe that as a matter of general policy, the FCC should continue to evaluate claims of harmful interference using the metric that the GNSS industry, the FCC, and the National Telecommunications and Information Administration ("NTIA") have used in various contexts for many years – whether there is a 1 dB decrease in the C/N_0 of the affected receiver. Based upon well understood GNSS engineering considerations, a 1 dB change is associated with quantifiable changes in the overall noise to which GNSS receivers are subject, with equally well understood effects on receiver operation. Use of this standard is necessary to ensure the accuracy, integrity, continuity, and availability of the GNSS signal.

The NASCTN data, with respect to the relatively small sample of receivers tested, show direct correlation between a 1 dB drop in C/N_0 and degradation of the KPIs analyzed. The NASCTN testing program, however, highlights the difficulty of both measuring interference effects on KPIs and the variability of test results. Moreover, failing to gauge GNSS performance based on a universal, quantifiable metric that accounts for all uses and variations in signal would undermine technological innovation by subjecting the design and development of future equipment to tremendous uncertainties about the amount of "noise" present in the radiofrequency environment. Use of the 1 dB standard has allowed GPS to thrive and all GNSS systems to serve a critical role in ensuring safety-of-life services and propelling economic growth.[7]

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[6] The agreements entered into by Deere and Garmin also include provisions regarding the technical requirements for use of the 1526-1536 MHz band. *See* LightSquared December 8 *Ex Parte* at 2-3; LightSquared December 17 *Ex Parte* at 19-23. The agreement entered into by Trimble does not. Comments of Trimble Navigation Limited at 2, IB Docket No. 12-340, *et. al* (filed May 23, 2016).

[7] "The carrier-to-noise power ratio, C/N_0, is an important factor in many GPS receiver performance measures. It is computed as the ratio of recovered power, C, (in W) from the desired signal to the noise density N_0 (in W/Hz)." Betz, Hegarty, and Ward, *Satellite Signal Acquisition, Tracking, and Data*

A. The 1 dB Standard Is Supported by Well Understood and Critical Aspects of GNSS Engineering

For GPS and GNSS systems to meet the needs of existing and future users, it is essential that they be able to deliver a signal that is accurate, has integrity, and is available and continuous in nature. The same four attributes – accuracy, integrity, availability, and continuity – are affected by interference in varying ways, and degradation of any one of these four performance parameters will diminish the usefulness of GNSS to significant numbers of users.[8]

Accuracy is the difference between a GPS device's indicated position, velocity, and time ("PVT") and its actual PVT at any given moment. The accuracy requirements are highly use-case dependent, varying from tens of meters to less than a centimeter. In earthquake monitoring, for example, accuracy is extremely important both for measuring the imminence of quakes and for calculating post-quake displacement.[9] Survey GNSS, precision agriculture, and intelligent transportation systems could not continue to function without accuracy. Yet, accuracy alone is insufficient for most GNSS applications; they also need integrity, availability, and continuity.

Integrity is the ability of GNSS systems to provide *timely* warning to users of problems in the system or equipment and to shut itself down when it is unable to meet accuracy requirements. Safety-of-life aviation operations, such as precision approach and landing as well as Terrain Awareness Warning Systems ("TAWS"), depend on integrity of the signal and system to avoid disasters and prevent loss of life. Without integrity, airport safety records would be worse and controlled flight into terrain accidents would rise.[10] Like accuracy, integrity alone is insufficient to ensure functioning of GNSS.

Demodulation, in UNDERSTANDING GPS PRINCIPLES AND PRACTICE, 185 (C. Hegarty and E. Kaplan, eds., Artech House 2006).

8 "Non-interference with radionavigation RF spectrum is crucial. All domestic and international radionavigation services are dependent on the uninterrupted broadcast, reception and processing of radio frequencies in protected radio bands. Use of these frequency bands is restricted because stringent accuracy, availability, integrity, and continuity parameters must be maintained to meet service provider and end user performance requirements." DEP'T OF DEFENSE, DEP'T OF HOMELAND SECURITY, AND DEP'T OF TRANSPORTATION, 2008 FEDERAL RADIONAVIGATION PLAN, at 1-14, http://www.navcen.uscg-.gov/pdf/2008_Federal_Radionavigation_Plan.pdf.

9 For background on U.S. utilization on GPS in earthquake monitoring and warning, *see generally* D.D. Green, et al., *Technical Implementation Plan for the ShakeAlert Production System in An Earthquake Early Warning System for the West Coast of the United States*, U.S. Department of the Interior, U.S. Geological Survey (2014).

10 "It is important to note that the mandatory installation of TAWS into U.S. commercial aircraft is considered by many to have made the single greatest impact to improving U.S. commercial aviation safety in the last 20 years." Letter of Michael P. Huerta, Acting FAA Administrator, to The Honorable Lawrence E. Strickling, Administrator, NTIA, Jan. 27, 2012, https://ntl.bts.gov/lib/44000/44300-/44302/06_NTIA_Letter_Enclosure_4_-_2012_Jan_25_-_StatusReportAssessOfPlanned_LSQ_ATC_-TransIn1526to1536MHz_-_FAA.pdf.

Availability describes how often a GNSS system is available for use when it satisfies accuracy and integrity requirements. A GNSS-based service that only provides PVT information with high integrity for short and unpredictable bursts is unsuitable for most applications. For example, even a momentary degradation of service during an aircraft precision approach or flight close to terrain may trigger a missed approach procedure requiring a pilot to climb to a safe altitude and then wait to be readmitted to the landing sequence. Simply put, all, if not most, ongoing uses require changes or suspension of operations if GNSS becomes momentarily unavailable. Data show that GPS, as it currently functions, meets service availability requirements nearly 100% of the time.[11]

The fourth attribute, *continuity*, evidences GPS's ability to provide the required level of service without unscheduled interruption. Momentary episodes of interference can significantly disrupt continuity for many use cases or applications. Providing high levels of continuity in the face of unpredictable and random interference is particularly difficult and may make potential applications of GNSS unviable. For example, the time between unscheduled interruptions must be long to ensure that standard surveying operations can be conducted, driverless cars can navigate down the highway, and ambulances can reach unfamiliar destinations.[12]

Critical engineering considerations associated with GNSS receivers highlight the potential for degradation in performance in the presence of interfering noise. GNSS, as a navigation system, operates differently than radio communications systems. The primary measurement in GNSS is the timing of bit transitions in the navigation signal. Precise timing and positioning requires sub-nanosecond measurement of bit edges. Accurate measurement of bit edges, in turn, requires wide receiver bandwidth. Also, effective multipath rejection requires wideband signals to discriminate between those signals directly from the satellites versus those undesired reflected signals. Unlike communications systems, which operate above the noise floor, spread spectrum GPS signals are below the thermal noise floor when they are received.[13] The cumulative effects of interference can easily increase the noise floor and degrade performance. Even a small increase in the noise floor may affect any one of the four parameters of accuracy, integrity, availability, or continuity in unexpected or dramatic ways. Each of the attributes can be degraded by varying amounts.

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[11] *See* WM. J. HUGHES TECHNICAL CENTER, GLOBAL POSITIONING SYSTEM (GPS), STANDARD POSITIONING SERVICE (SPS), PERFORMANCE ANALYSIS REPORT, REPORT #92 (2016), http://www.nstb-.tc.faa.gov/reports/PAN92_0116.pdf.

[12] These four performance attributes are internationally recognized and defined. For instance, in 2001, the International Civil Aviation Organization adopted "Standards and Recommended Practices" or "SARPs" that, since 2001, have both defined and set requirements for provision of accuracy, integrity, availability, and continuity of GNSS signals by member countries. *See, e.g.*, Amendment 76 to the International Standards and Recommended Practices and Procedures for Air Navigation Services, at Table 3.7.2.4-1. Furthermore, other international bodies have also recognized the requirements for accuracy, integrity, continuity, and availability. *See* ITU Recommendation ITU-R M.1477, Annex 5 at Section 4; see also European GNSS Agency, "Report on the Performance and Level of Integrity for Safety and Liability Critical Multi-Applications," May 2015, at 11, http://www.gsa.europa.eu/sites/-default/files/calls_for_proposals/Annex%202.pdf.

[13] *See* UNDERSTANDING GPS PRINCIPLES AND PRACTICE, *supra* note 6, at 247.

GNSS system operators and the GNSS industry have found that monitoring changes in a receiver's C/N_0 provides a quantifiable and empirical measure of receiver performance that directly influences all of the four attributes. C/N_0 is directly related to signal to noise ratio ("SNR") and bit error rate ("BER") and is the actual measure of noise and stress in tracking loops.[14] So like BER and SNR, C/N_0 is a direct measurement of receiver performance, rather than a downstream measurement of use-case dependent parameters (such as position error) and is therefore the most appropriate parameter for consideration in an interference analysis. Use of C/N_0 as an interference metric also allows system designers and spectrum regulators to carefully allocate interference to various sources as the net effect of interference is the sum of the individual interference sources, each of which has been expressed in dB. Use of C/N_0, in other words, permits both aggregation of interference and the apportionment of interference among multiple sources.[15]

A 1 dB decrease in C/N_0 is associated with quantifiable changes in the noise to which GNSS receivers are subject, as well as quantifiable effects on performance related variables. A decrease of 1 dB in C/N_0 produces roughly a 25 percent increase in noise due to interference. In many contexts, degradation of 1 dB or more is sufficient to convert acceptable service to marginal service.[16] For example, a 1 dB reduction in C/N_0 from the minimally acceptable operating point will push the Wide Area Augmentation System ("WAAS") word error rate ("WER") above the maximum allowable level of 10^{-3} for certified aviation devices.[17] And while the NASCTN test simulated two WAAS satellites, it did not measure the impact of interference on WER. WAAS represents a carefully engineered component of the GPS system in which the effects of many attenuation and interference sources have been taken into account to reach an operating point that meets strict requirements. Reducing C/N_0 by 1 dB causes the system to no longer meet those requirements.

A 1 dB reduction in C/N_0 is also associated with a tenfold decrease in mean time between cycle slips. Most GNSS systems rely on continuous tracking of the signal carrier of each satellite being tracked to attain maximum accuracy. By continuously tracking the carrier and measuring its phase at the time of measurement (the carrier phase), relative motion with respect to the satellites can be measured to sub-centimeter levels. A cycle slip interrupts this continuous carrier phase, forcing the tracking loop to reacquire the carrier, and then re-initiating the carrier

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14 As experts note, "[a]n accurate measure of C/N_0 in each receiver tracking channel is probably the most important mode and quality control parameter in the receiver baseband area." *Id*. at 233.

15 M. RICHHARIA, SATELLITE COMMUNICATIONS SYSTEMS DESIGN PRINCIPLES, 102 (McGraw-Hill 1995) ("The total noise at the receiver is the summation of noise from all sources . . . . ").

16 Memorandum from National Space-Based PNT Executive Steering Group to Administrator, NTIA, June 14, 2011, at 4, https://www.ntia.doc.gov/files/ntia/publications/ligtsquared_assessment_-report_07062011.pdf.

17 RTCA DO-327, Section D.1.5.

phase measurement. Lack of continuous carrier phase renders many high precision applications unavailable.[18]

In addition, all GNSS applications track the pseudo random noise code ("PRN code") from selected satellites in view – this is accomplished in the code tracking loop. The code tracking loop synchronizes a locally generated replica PRN code with the PRN code broadcast from the satellite. This synchronization allows the receiver to make a precise measurement of the starting edge of the first bit of the PRN sequence as it repeats. With this code phase information, the receiver can determine how long it took the satellite signal to reach the receiver and consequently the distance to the satellite. As the noise floor rises, the increased noise makes it more difficult to precisely synchronize the replica PRN code to the broadcast signal, resulting in increased error in the measured distance to the satellite. In dynamic applications with wider tracking loop bandwidths, small increases in the noise floor yield substantial changes in Coarse Acquisition code tracking error, especially in reduced signal scenarios in which the receiver is operating close to its acquisition sensitivity threshold.

Degradation as a result of increased noise may occur before the point at which there has been a 1 dB reduction in C/N_0, or, that is, before the point at which the noise due to interference has increased by 25 percent. This is particularly true in challenging use cases in which signal levels may be attenuated by foliage or structures (for example, suburban streets or "urban canyons," respectively), or in which signal reception is changing due to dynamic effects, such as large trucks passing on the highway or aircraft "pitch and roll" during normal maneuvering at takeoff, landing, or en-route. It is critical that the margin established in the design of the GPS system for effects such as these not be eroded by allowing interference levels (only measured in

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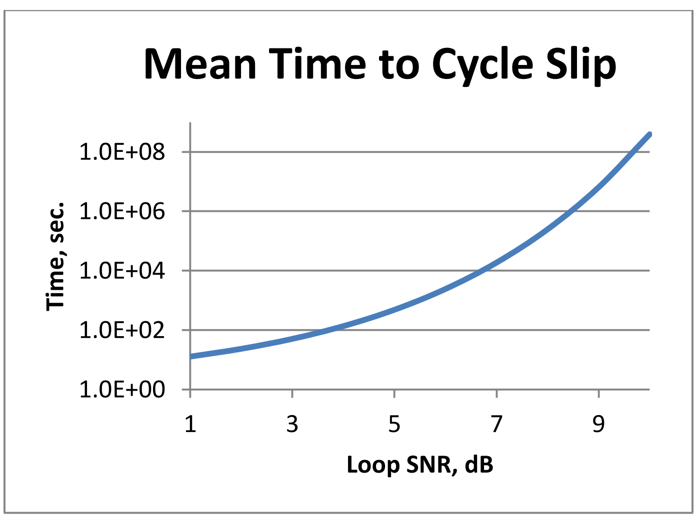
[18] As shown in the chart in this footnote, the average time between cycle slips, or disruptions in carrier phase, which cause measurement reinitialization, decrease by an order of magnitude with a 1 dB reduction in loop SNR (which tracks directly with C/N_0). In other words, cycle slips occur 10 times more frequently when C/N_0 is reduced by 1 dB. This chart is based on the equation $\tau=\pi^2\alpha I_0(\alpha)/2B_L$, where α is the signal to noise ratio, B_L is the loop bandwidth and τ is the mean time to cycle slip. W. LINDSEY AND C. CHIE, PHASE LOCKED LOOPS, at p. 24 Formula 47 (IEEE Press 1986).



ideal conditions) to cause degradation to the GPS system in excess of the 1 dB standard. This point is substantiated by NASCTN test results showing more rapid degradation of performance metrics with increasing noise in "distressed" environments.

Given these characteristics and fundamental benefits, C/N_0, as an indicator of interference, not surprisingly has a long history of use not only in navigation, but also in radar and communications. For example, radars operating in the radiodetermination service bands are similarly affected by interference and quantify it in terms of the interference to noise ratio.[19]

B. The NASCTN Tests Provide Limited Additional Data

According to recent estimates, there are approximately 750 million GNSS receivers in use in North America.[20] While estimates of the number of unique types of devices in use are not available, it would not be unreasonable to estimate that, at least tens of thousands of different GPS receiver and antenna combinations types are in use. NASCTN tested fourteen unique devices and twenty configurations of GNSS receivers.[21] As the NASCTN report acknowledges, "[t]he distribution and quantity of units, models, or manufacturers necessary to achieve a DUT population that is 'representative' of this complete market has not been established. The relationship between the comprehensive market and our test population (or that of previous tests) is therefore not clear."[22] The NASCTN Report also did not attempt to compare its test results to prior tests, or analyze any differences, as the Report notes:

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[19] "If power spectral density of radar-receiver noise in the absence of interference is denoted by N_0 and that of noise-like interference by I_0, the resultant effective noise power spectral density becomes simply I_0+N_0. An increase of about 1 dB would constitute significant degradation, equivalent to a detection-range reduction of about 6%. Such an increase corresponds to an (I + N)/N ratio of 1.26, or an I/N ratio of about –6 dB." *See Recommendation ITU-R M.1463-3, Characteristics of and Protection Criteria for Radars Operating in the Radiodetermination Service in the Frequency Band 1215-1400 MHz*, INTERNATIONAL TELECOMMUNICATION UNION, at p. 8 Section 3 (2015).

[20] 5 EUROPEAN GNSS AGENCY, MARKET REPORT 33 (2017), https://www.gsa.europa.eu/system/files/reports/gnss_mr_2017.pdf.

[21] The NASCTN LTE tests included five GLN receivers, three of which provided useable C/N_0 data while under test, and six High Precision (HPP) receivers, of which four were unique models (*i.e.*, two were the same model). For HPP standalone receivers, there are test results for 5 configurations, DUT 7 to DUT 10. NASCTN also tested RTK devices as a subset of HPP devices with additional features. There were four RTK receivers, representing two manufacturers. Two of the four RTK receivers served as rovers, and the remaining two served as base stations. For RTK receivers, there are test results for four combinations of two receiver models and two antenna models, DUT 11-Ant A, DUT 11-Ant B, DUT 12-Ant C, and DUT 12-Ant D. For comparison, the Department of Transportation tested 18 GLN and 35 HPP receivers in its Adjacent Band Compatibility study. *See Test Plan to Develop Interference Tolerance Masks for GNSS Receivers in the L1 Radiofrequency Band (1559-1610 MHz),* DEPARTMENT OF TRANSPORTATION (2016), https://ntl.bts.gov/lib/55000/55400/55473/Draft_DOT_GPS_Adjacent_Band_Compatibility_Assessment_Test_Plan.pdf.

[22] NASCTN Report at 1.

> "Comparison among results of different test campaigns . . . requires an understanding of any differences in test conditions, devices, and parameters. Specific examples include GPS and LTE signal parameters, power levels, and test environments. Understanding these factors is crucial to drawing conclusions based on the aggregate of these heterogeneous test results. These types of analyses are beyond the scope of this project, but may be undertaken by other interested parties such as the GPS and cellular communications industry, government agencies, or spectrum regulators."[23]

In terms of the test methodology itself, the NASCTN tests analyzed effects on GNSS receivers in only a single fixed position in the lab. Thus, no measurements of velocity, acceleration, or jerk performance and their effects on KPIs were taken.[24] Since the vast majority of GNSS receivers are intended to be used in mobile applications, this is a substantial limitation, and the effects of including dynamic tests as well are unknown.

C. The NACSTN Data Support the Use of the 1 dB Standard

For the reasons discussed above, 1dB degradation would be expected to adversely affect multiple user metrics, including acquisition time and position accuracy. Though not directly measured by NASCTN, availability, integrity, and continuity are all affected by degradation of acquisition time and accuracy.[25] In fact, the NASCTN test data show a clear correlation between C/N_0 degradation and the other metrics evaluated and therefore support the use of the 1 dB standard to determine harmful interference. The test results also show increased effects of changes in C/N_0 in "stressed" test conditions which are more likely to represent real world conditions in many cases.

Time To First Fix ("TTFF") performance is vital to users of high-precision receivers. Until it attains signal tracking and position fix (*e.g.*, TTFF), a receiver does not produce a useful position measurement, so position accuracy alone is not an indicator of user performance capability. TTFF affects the total availability of use of the high precision position information. The need for increased time to re-acquire satellites and to fix cycle ambiguities on a high precision receiver can significantly degrade performance to the users. Many high-precision applications on heavy machinery require availability near 100% for users to gain full utility and productivity from their equipment.

With respect to High Precision receivers, comparison of the C/N_0 plots with the TTFF measurements for HPP and RTK receivers in the NASCTN results shows that TTFF performance degradation is concurrent with an interference-induced 1 dB drop in C/N_0.[26] Based on these estimates, the level of LTE interference that affects TTFF occurs on average within

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23 *Id.*

24 Velocity is the first derivative of position with respect to time, acceleration the second derivative, and jerk the third derivative. Thus, measuring position in a static simulation without considering these derivative effects limits the utility of the NASCTN data.

25 Accuracy was not assessed in any significant or meaningful way since no dynamic testing was performed. In addition, NASCTN only measured position accuracy.

26 *See* Appendix, Table1.

approximately 3 dB of the 1 dB C/N_0 degradation point, showing a clear connection between signal reception, as measured by C/N_0, and the user experience with respect to TTFF.

The NASCTN test results also show a close correlation between degradation in C/N_0 and the positional accuracy of GLN receivers tested. The test results highlight a significant limitation on the test methodology using devices in a stationary position, which distorts results for devices with certain filter characteristics. DUT 3, Figure 6.21 (page 142) is a good example of when the position error begins to increase at the same time the C/N_0 begins to degrade in the presence of the interfering signal. Upon close examination, the position error begins to increase at about -20 dBm of LTE power incident upon the DUT. This correlates well to figure 6.20 (page 141), where DUT 3 shows a C/N_0 degradation at the same power level. DUT 3, Figure 6.21 also clearly shows how the position error grows significantly as the C/N_0 degrades in the presence of noise, actually reaching nearly 40 meters at the limit compared to a baseline of approximately 0.5m.

DUT 1, Figure 6.21 (page 142) at a cursory reading seems to indicate position error is reduced in the presence of severe interference. Under the laws of physics, however, the error in a measurement increases as the signal to noise ratio of the signal decreases. This is where knowledge of the implementation of the GPS receiver's positioning filtering becomes critical. In the case of DUT 1, as the level of interference increases and the C/N_0 decreases, the positioning filter begins to significantly de-weight the measurements with lower C/N_0 and "pin" its reported position to the last known position when the measurement noise was lower.[27] This technique only produces reasonable results when a GPS receiver is stationary and is a critical reason why any sort of use-case or KPI testing must include a dynamic scenario, not just a stationary one.

Further, with about -15 dBm of LTE power incident upon DUT 1, its "pinned" position jumps to a new position which is of greater error. Later in the test, the "pinned" position jumps back to a lower error position. This behavior is also apparent in DUT 2, Figure 6.21 (page 142). More examples of position pinning are apparent in the GLN results in Section 6.5 ("LTE Power Level Sweeps for Limited GPS Power Exposure").

The NASCTN testing also demonstrates greater negative impacts of potential interference in scenarios when GPS signal power and number of satellites are limited.[28] The NASCTN test program's "limited" GPS scenario represents more real-world conditions than the nominal GPS scenario with full-power on all satellites.[29] GPS receivers are expected to operate well in

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[27] As the interference increases, the positioning filter will actually start to reject measurements, which paradoxically may lower the overall positioning error if the "pinned" position is a good estimate of the actual position.

[28] *See* NASCTN Report Section 6.5, at 233-59.

[29] *See* NASCTN Test Report at Section 2.2.2, at 20-22 for a detailed description of the GPS constellations simulated in the NASCTN test. The "limited" scenario for positioning receivers was an adjustment to the "normal" nominal scenario constellation and has reduced power and fewer satellites. This exposure stressed the ability of GPS receivers to acquire lock through reduced C/N_0 levels. The adjusted constellation was limited to eight L1 C/A and two WAAS signals. The satellite exposure levels at the DUT were distributed across four target values – a pair of satellites at each of -128.5 dBm, -133.5 dBm, -138.5 dBm, and -143.5 dBm EIIP at the DUT (in test implementation, satellite exposure values

obstructed signal conditions as might be encountered in a downtown "urban canyon" or under dense tree cover. In these situations, the number of satellites in view, as well as their C/N_0, can be significantly reduced. In this test scenario, the satellite power levels varied from nominal to 15 dB below nominal in 5 dB steps. This test scenario clearly illustrates the point that every dB of C/N_0 is valuable – it could be the difference between having a fix or not having one.

For example, in Figure 6.111 (page 236), DUT 1 exhibits the "position pinning" behavior clearly as the position filter in this device struggles to process weak signals, several of which are at reduced C/N_0. Conversely, DUT 3 in Figure 6.111 also exhibits the position pinning behavior, but in this case, it pins its position to the correct position solution for the entire test. As stated previously, a dynamic test in this limited GPS signal environment would have been illustrative of the effect of reduced C/N_0 on the position accuracy of the devices. In Figure 6.116, when UL1 is tested, the results exhibit both position pinning behavior in DUT 1, and the more straightforward increase in position error as the C/N_0 decreases in DUT 2 and DUT 3.

The NASCTN "limited" GPS scenario results for HPP and RTK receivers are shown in Table 2, labeled as the "stress" results for each DUT. These results show that the 1 dB C/N_0 result is fairly consistent compared to the nominal constellation results (per DUT). For example, DUTs 7, 8, 9-Ant C, 9-Ant D in Figure 6.26 (page 147) all had nearly the same 1 dB C/N_0 value for nominal and unstressed constellations. This validates the use of 1 dB C/N_0 as the most appropriate metric of receiver performance when exposed to interference, as it is consistent across the widest range of GPS constellation conditions.

After close inspection and review, the NASCTN data actually illustrate a major difference between the nominal and stressed constellation scenarios: the occurrence of "no lock," which happens at a much lower interference level, for all receivers when the GPS constellation is stressed. For example, in Figure 6.121 (page 246), DUT 8 has a "no lock" value 11.6 dB lower for the stressed constellation than the nominal, and DUT 10 has a "no lock" value 15.3 dB lower for the stressed constellation than the nominal. Any other metric (such as position error) would vary with constellation stress in similar manner to the "no lock" condition. Consequently, such a test would yield different results for every GPS operating condition. Any metric that does not produce consistent results despite normal variations in the constellation is not appropriate for gauging receiver performance.

IV. <u>Conclusion</u>

The NASCTN test results confirm what GPSIA has said all along: the historic standard for determining harmful interference – whether an interfering signal produces a 1 dB decrease in the C/N_0 of the affected receiver – continues to be the most appropriate metric for assessing the impact on GPS. The standard is well supported by precedent and is also based upon well understood technical characteristics of GNSS receivers and the impact of noise on the performance of these receivers.

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were -128.5 dBm 2.7 dB, -133.5 dBm 2.7 dB, -138.5 dBm 2.7 dB, and -143.5 dBm 2.7 dB EIIP at the DUT).

Pursuant to Section 1.1206(b)(2) of the Commission's rules, an electronic copy of this letter is being filed for inclusion in the above-referenced dockets. Please direct any questions regarding this filing to the undersigned.

Very respectfully,

/s/ F. Michael Swiek

F. Michael Swiek
Executive Director

APPENDIX

Table 1: Comparison of 1 dB C/N_0 degradation versus interference level affecting TTFF, derived from NASCTN plots

Rcvr Type	LTE Type	C/No Plot	TTFF Plot	DUT 7 (HPP) C/No/TTFF	DUT 8 (HPP) C/No/TTFF	DUT 9-C (HPP) C/No/TTFF	DUT 9-D (HPP) C/No/TTFF	DUT 10 (HPP) C/No/TTFF
HPP	DL	Fig 6.25; pg. 146	Fig 6.99; pg. 223	-65/-61.2	-70/-63.4	-60/-52.3	0/-1.5	-65-62.5
HPP	UL1	Fig 6.30; pg. 151	Fig 6.105; pg. 229	-45/-46.3	-55/-51.3	-50/-50.0	-35/-33.8	-55/-47.2
Rcvr Type	**LTE Type**	**C/No Plot**	**TTFF Plot**	**DUT 11-A (RTK) C/No/TTFF**	**DUT 11-B (RTK) C/No/TTFF**	**DUT 12-C (RTK) C/No/TTFF**	**DUT 12-D (RTK) C/No/TTFF**	
RTK	DL	Fig 6.50; pg. 171	Fig 6.107; pg. 231	-70/-67.0	N/A / N/A-24.6	-60/-54.3	-5/-1.3	
RTK	UL1	Fig 6.55; pg. 176	Fig 6.101; pg. 225	-60/-59.7	-20/-15.4	-50/-48.5	-40/-33.4	

To perform this comparison, the 1 dB C/N_0 values and the interference level at which TTFF increased for each test were drawn from Table 6.2, page 220, as well as estimated from the plots in the NASCTN report (as noted in the Table 1). The estimated points for each test are presented in the figures included as Table 3. Table 1 shows a summary of the 1 dB C/N0 values and the effect on TTFF performance.

Table 2: Tabular summary of NASCTN results for HPP and RTK receivers

		LTE DL 1526MHz – 1536 MHz No Lock [dBm]	LTE UL1 1627.5 MHz – 1637.5 MHz No Lock [dBm]
DUT 7	Nom	-34.8	-31.3
	Stress	-39.9	NA
DUT 8	Nom	-45.8	-33.8
	Stress	-57.4	-36.6
DUT 9-Ant C	Nom	NA	-29.6
	Stress	NA	-34.6
DUT 9-Ant D	Nom	NA	-13.8
	Stress	NA	NA
DUT 10	Nom	-37.8	-25.3
	Stress	-53.1	-33.2
DUT 11-Ant A	Nom	-54.3	-32.8
	Stress	-57.2	NA
DUT 11-Ant B	Nom	NA	NA
	Stress	NA	-8
DUT 12-Ant C	Nom	-39.9	-40.1
	Stress	No fix	No fix
DUT 12-Ant D	Nom	3.1	-15.3
	Stress	No fix	No fix

Table 3: Sources of data for Table 1

	HPP	RTK
Nominal GPS constellation	Figures 6.25, 6.26, 6.29, 6.30, 6.34, 6.35, 6.39,6.40	Figures 6.49, 6.50, 6.55, 6.56, 6.59, 6.60, 6.64, 6.65
Stressed GPS constellation	Figures 6.119, 6.120, 6.124, 6.125	Figures 6.129, 6.130, 6.134, 6.135